Final

DSMS Operations Concept

Gary L. Spradlin

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California
gary.l.spradlin@jpl.nasa.gov

Abstract

The Deep Space Mission System (DSMS) Operations Concept provides a vision of the future for deep space mission operations. In general, the concept illustrates a steady evolution toward a reliable and highly automated Deep Space Mission System, and deployment of the full set of the services offered by the Telecommunications and Mission Operations Directorate (TMOD) Services Catalog. It discusses the movement to a station-centric architecture and its implication for operations, principally a shift of responsibility, control, and performance accountability to the point of service execution at the tracking complexes. The service management system functions that enable customers to easily use low cost multimission capabilities to satisfy their mission support requirements are also discussed.

The concept provides an overview of operational roles and responsibilities in a service system environment. It describes changed and new interfaces between the customers and the service system, and variations on these interfaces as a function of the level of support required by the customer.

Introduction

The DSMS Operations Concept is a lengthy document, and significant summarization has been necessary to provide an overview within the constraints of this paper. Thus, summary-level detail provided here will focus on key aspects of the operations concepts; readers are advised to contact the author if interested in a complete copy of the document.

The DSMS is a service system providing mission operations services primarily to deep space flight projects. It is comprised of data system elements (i.e., hardware and software), and operational teams which are multimission, and it includes both ground-based service elements and flight-based elements when these are provided by TMOD. The DSMS operations concept is intended to be:

- Visionary - looking down stream ten years
- All-encompassing, i.e., spanning all of TMOD's operational responsibilities
- The guiding document providing context and precedence for DSMS subsystem-level operations concept development, as well as, providing insight for DSMS-using projects, as they develop their own mission-oriented operations concepts
- A source/reference for operations requirements and a basis for DSMS design and service system interfaces
- A living document, updated annually

DSMS Operations Vision

The DSMS Operations Concept includes a series of vision statements providing snapshots of the DSMS, from an operations perspective, as it evolves over the next ten years. These snapshots can be distilled into a before and after statement as shown in Figure 1 that serves to contrast the DSMS of today and the DSMS of the future.

✦ **Today**	✦ **The Future**
➢ Planning for support is done by negotiations for all levels of support, support agreement is customized	➢ Planning for support is done via a service catalog, and using standard services when possible
➢ Scheduling centrally done, labor intensive, many meeting/iterations, customer fully involved from start to end of process and schedules at the asset-level	➢ Scheduling done via SR, schedule optimization/resources allocation automated, missions have agreed priorities, asset scheduling done at the DSCC near time of SR execution, Manual intervention possible but not normal
➢ Activities are driven by detailed keyword files either provided by the customer or generated by DSMS operations	➢ Activities are driven by high-level SR, expansion of the SR occurs at points in the system where details become important
➢ Predicts are centrally done, batch processed, just-in-case, and labor intensive, not responsive to schedule updates near time that the service is rendered	➢ Predicts are generated via an automated process at the DSCC, created near to time of SR execution (JIT), very responsive to scheduling updates
➢ Automation based on nominal activities, no recovery capability for exceptions, operators control multiple links, and control is operator intensive	➢ Control of each link is via a dedicated controller, is highly automated, generally no operator intervention at the link-level, operators primary interface is via the Complex Supervisor
➢ No service accountability, only high-level metrics	➢ Each station is accountable for service execution, providing high-level visibility and controllability to the customer, customer has little need to monitor SR execution
➢ Customers feel the need to "be in the loop" at all times to assure that they get what they asked for, customer must have detailed knowledge of DSMS operations, equipment capability, and they require extensive status reporting	➢ Customer makes high-level requests, has no need to be a DSMS "expert", and does not need to micro-manage the DSMS
➢ Blurred authority, responsibility and accountability distinctions	➢ Clearly defined authority, responsibility

Figure 1 - Vision of the Future

DSMS Architecture and Operational Features

The DSMS Operations Concept provides various views of the DSMS in order to illustrate key aspects of the DSMS not apparent in a single view. Presented here is the Architectural View. The Architectural View illustrates how the key internal components of the DSMS function and enable TMOD to provide support committed to a DSMS customer.

The Architectural View provides a look at the inner workings of the DSMS. In particular this view illustrates the station-centric nature of the DSMS. The view includes detail about how the DSMS is organized and how key internal components function to enable the DSMS to support its customers.

In Figure 2, four fundamental components are shown, the Project Mission Operations Center (or Customer), JPL Central, the station-centric DSCC, and the customer's spacecraft. Several concepts are apparent from this top-level view as follows:

- JPL Central has two primary roles, one at the customer interface to aid the customer in the use of the service system, and the second role to provide the home location for some of the services, e.g. flight engineering service, that require expert knowledge and application-specific tools.
- The DSCC is composed of several logical stations. A station is a mixture of station-dedicated assets, e.g., the antenna; complex-assignable assets, e.g., Downlink Subsystem;

and shared assets, e.g., the Frequency and Timing Subsystem. Each station includes support for core services (telemetry, etc.), and these services interface directly with the customer.

- There is extensive use of communications standards.

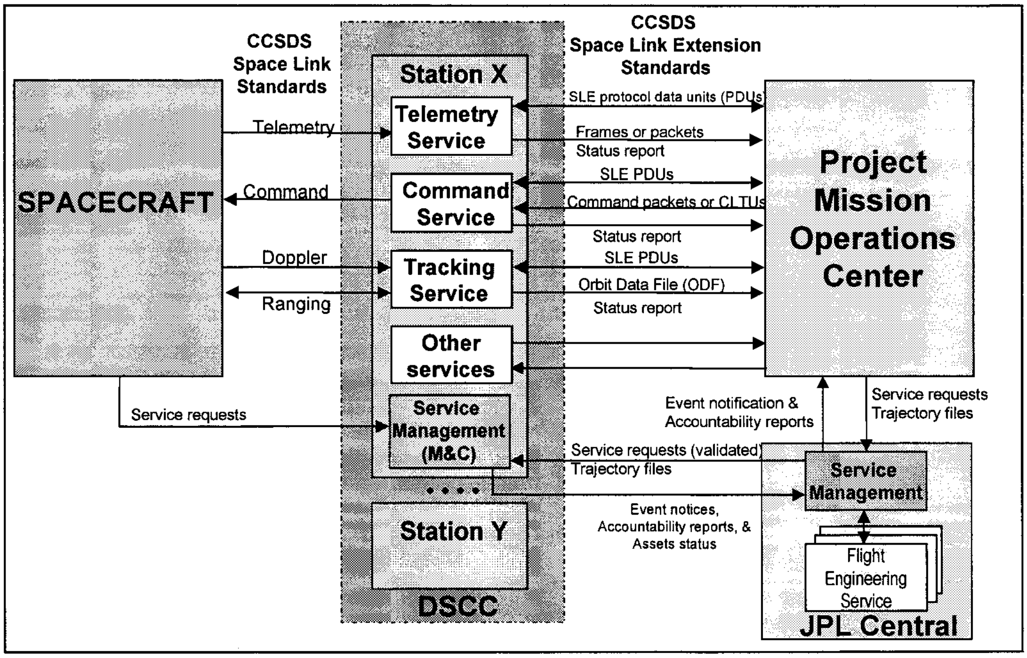


Figure 2 - Architectural View

Key attributes of station-centric architecture include:

- Each station is a self-contained operation and is driven by customer service requests.
- A service management capability providing predicts generation, asset scheduling, and other support data required to configure for support and perform scheduled activities.
- The station is capable of performing closed-loop control of all assets required to support a service instance, assuming nominal operations.
- The station provides a direct customer interface for services. Telemetry and tracking data are transmitted directly to the customer, and command data are received directly from the customer for uplink transmission.
- Each station provides service performance accountability.
- Each station is robust, averaging no more than one anomaly requiring human intervention for every three months.
- Station operations are largely unattended (there are exceptions).
- The station provides a direct interface for use of the station as a science instrument.
- All missions are supported using standard interfaces.
- The station is supported by a communications and facilities infrastructure.

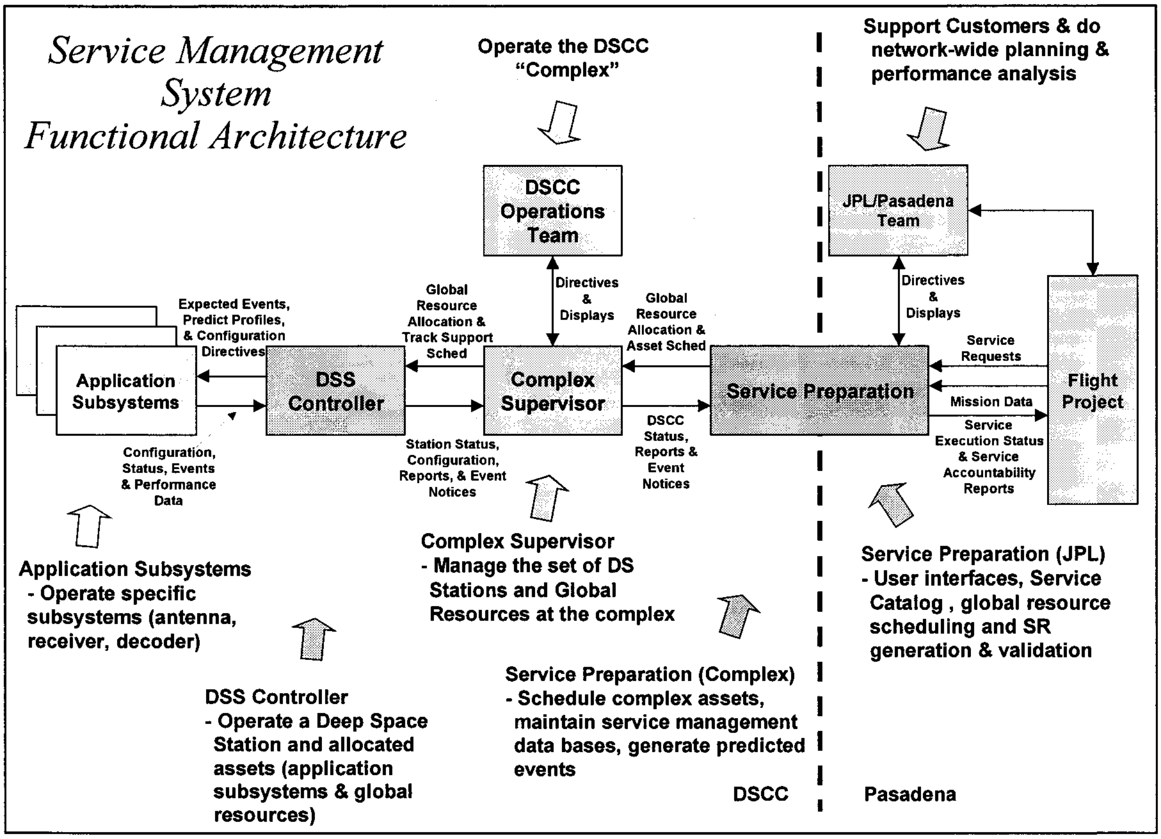


Figure 3 - SMS Functional Architecture

Service Management

A service system must, of necessity, include a mechanism for managing and reporting on the services that comprise the system; thus the DSMS includes a Service Management System (SMS). Figure 3 provides detail illustrating how the SMS functions to support DSMS service planning and service use within the station-centric architecture. This illustration includes several boxes representing key components of the SMS, and is intended to illustrate the monitor and control architecture of the DSMS. Not shown is the flow of customer data (telemetry and command data) to/from the spacecraft. Scheduling and control of activities flow from right to left via service requests made by customers. Performance reporting flows from left to right.

Service Preparation provides the customer interface with the DSMS. It processes service requests, supports commitment of DSMS resources needed to satisfy a service request, and provides service performance reports. Service Preparation provides a resource plan to the Complex Supervisor. The Complex Supervisor is responsible for controlling the assets located at each deep space tracking complex. As the time of actual service delivery approaches it assigns physical assets (antennas and other elements of the service system) as required to support that instance of service. In the nominal case, asset allocation can be handled automatically by the Complex Supervisor, however, complications or exceptions may require active participation by the DSCC Operations Team, and less frequently, by JPL/Pasadena Team.

Station control is provided by the DSS Controller. There is a DSS Controller for each station that is responsible for running service instances (tracks) as required to satisfy customer service requests (this is the essence of the station-centric architecture). The DSS Controller receives high-level mission directives, schedule, and event information from the complex level. Radio metric and telecommunications predictions and other information needed to calibrate and control Application Subsystems for a track are generated at the direction of the DSS Controller. The station operates autonomously and unattended with operator intervention possible but not usual. The nominal operations interface is provided by the Complex Supervisor where operators monitor the status of the DSS Controllers and complex-global assets. However, operator intervention may be required during exceptional conditions, e.g. critical mission events, spacecraft emergencies, or during some station failure scenarios, and an operator interface is available at the DSS Controller to support exceptional conditions when required. A maintenance interface is provided at the DSS Controller and at each Application System for off-line subsystem troubleshooting and maintenance.

Responsibility for performance and problem detection/recovery is partitioned and delegated to the lowest level practical throughout the SMS. Control loops operating within the Application Subsystems, the DSS Controller, and the Complex Supervisor have specific responsibilities to control performance within their domain. Detailed performance information available at the level at which it is generated with summary information passed up to the next level of the hierarchical structure. Local failure recovery is provided at each level with requests of assistance from higher level elements occurring only after failing to overcome problems at the level where the problem is detected. For example, if a receiver experiences a failure, the receiver subsystem is responsible for detecting this problem and providing recovery within available redundancy of the receiver. Failing to find a solution, the receiver passes the problem to the DSS Controller. The DSS Controller will attempt recovery within the assets allocated to it for the support instance. If this is not possible, the Complex Supervisor is contacted for a solution that may require reassignment of complex resources, or human intervention for assignment or reassignment of resources. It is also possible that the problem must be resolved at JPL Central where mission priorities may be adjusted to reallocate DSMS resources.

The DSMS Operations Concept includes an encompassing Service Quality Assessment concept that provides insight into the quality of the services being provided to the customer and into operational aspects that indirectly affect the service quality specifically, maintenance and logistics. This includes Performance Assessment and Maintenance and Logistics support for all capabilities at both the DSCC and JPL

Operations Roles and Operations Teams

The objective of this section of the operations concept is to logically organize the work done providing services to our customers. The organization is "badge-less," and ignores existing organizations, turf boundaries, how we currently do things, traditions, etc.

Operations Teams

Two super teams are illustrated in Figure 4:

1. The **Data Acquisition, Delivery & Management (DADM) Service Team** that supports activities focused on establishing and executing basic services.
2. The **Application Service (AS) Team** that represents a logical grouping of "like" activities providing customers with a spectrum of selectable capabilities and skills within a given core competency.

Figure 4 lists the characteristics that differentiate these two super teams from each other. Grossly, the AS team is very focused on performing a particular function. It is very data content-aware, and requires unique skills and tools to accomplish the functions it performs. The DADM Service team is focused on the basic performance of the DSMS, and the successful flow of data through the DSMS. It does not require detailed information about the meaning of the data flowing through the DSMS.

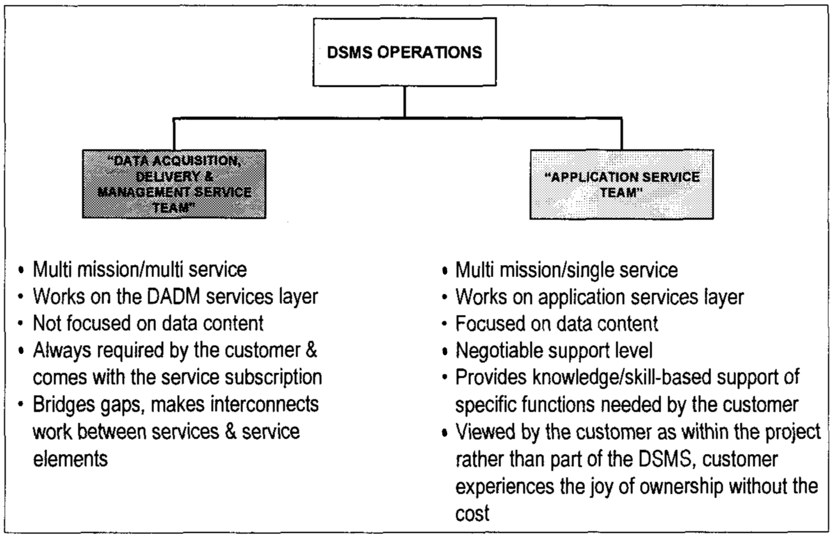


Figure 4 - The Two Super Teams

Role of DADM Service Team

The DADM Service Team is composed of three sub-teams: The Customer Service Team, the Infrastructure Team, and the Service Execution Team. The Customer Service Team provides the "people" point of contact for the customer with the DADM. It offers help with planning for and use of all aspects of the DSMS throughout the life of the mission, including planning for use of applications services. The Infrastructure Team provides the environment that the DSMS utilizes to support the customers use of the DSMS. The Service Execution Team is responsible execution of service requests and delivery of products to the customer.

The primary function of the DADM team is to assure that the DSMS services perform as required to satisfy commitments made to DSMS customers. The DADM team role in customer support begins at the earliest stages of development of a mission. The DADM team works with the customer during the concept development and proposal phase of a new mission, well before the mission achieves official status as an approved mission. During this pre-project phase, the DADM team helps the customer develop their mission operations concept, and select appropriate catalog-based services, tools, and other multimission engineering support for use during the mission.

The DADM team assists with the development of mission services requests to be utilized by the mission to orchestrate the services during the mission. The team assists the customer with development and demonstration of data processing and communications capabilities, and provides ongoing support throughout the mission.

Role of AS Team

The pressure on missions to reduce operations costs has caused many missions to consider some form of multi-project or multimission operations to keep costs as low as possible. Multi-project operations are defined to be operation of multiple spacecraft through sharing or partnering arrangements between Projects that have much in common, but maintain separate flight organizations and maintain/operate their own Mission Operations System (MOS). Multimission operations are defined as operation of more than one spacecraft by a single operations organization utilizing common MOS elements. The DSMS offers specialized engineering and analysis services via the Applications Team for missions that wish to take advantage of cost savings achievable through the use of either multi-project or multimission teams.

The AS team is composed of four sub-teams: The Navigation Team, the Flight Engineering Team, the Mission Planning & Sequencing Team, and the Science Operations Team. These teams provide specialized engineering support within their technical disciplines that may be subscribed to by a mission to varying degrees, i.e. the support level is negotiable.

A key difference between the DADM teams and the AS teams is that the DADM personnel are largely transparent to the customer, however, the Application Service teams are *very* visible to the customer. The DADM personnel do not require in-depth knowledge about a customer's mission design, science objectives, spacecraft characteristics, etc. However, the Applications Service personnel not only require this information, they may be the source of the information. These multimission teams eliminate or reduce the need for mission-dedicated personnel to perform the highly skilled functions of mission navigation, flight engineering, sequencing, and science operations support for the project. The teams maintain direct people to people interfaces within a subscribing project, functioning as "virtual" mission-dedicated teams, and take technical direction from the project management.

Role of the Mission Manager

TMOD has responsibility for conducting deep space mission operations performed at JPL. By being the center of mission operations, as well as, the provider of the services that missions rely on for mission support, TMOD is in a unique position to offer an additional type of support not actually located "within" any of the services. This support is provided through a TMOD Mission Manager (MM).

This position is normally one of several senior managerial positions within the Project's organizational structure, and the manager is typically mission-dedicated. The role for this position begins early in the life of the Project, and doesn't end until the mission has ended. The MM is responsible to the Project Manager for the development of a mission operations concept for the mission, the development of the MOS, and for execution of the mission. The MM will develop the MOS using elements of the DSMS whenever this is the most cost-effective approach for the Project.

Customer Interfaces

Basically, the DSMS offers customers two types of interfaces. All customers of the DSMS use the first interface, the Common Service Interface. It is primarily computer-based, but includes human intervention for exception handling, as well as, engineering and management support for pre-mission planning. Operationally, the Data Acquisition, Delivery, & Management Service Team supports the Common Service Interface.

For customers using only basic telecommunications services, e.g. telemetry, command, data management, etc., the Common Service Interface is the only interface needed for mission support. The Common Service Interface as illustrated in Figure 5 below consists of two functional components that support service management and data management. These will be explained in more detail below.

The second type of interface, the Extended Service Interface, describes relationships between customers and Applications Service Teams. This interface is very different from the Common Service Interface in that the nature of the interface depends very much on the services selected, the level of support to be provided within a selected service, and the operations concept for the mission to be supported. At a conceptual level, a description of the interface will look much like an organization chart. This will be illustrated below to help clarify the variations possible with the Extended Service Interface.

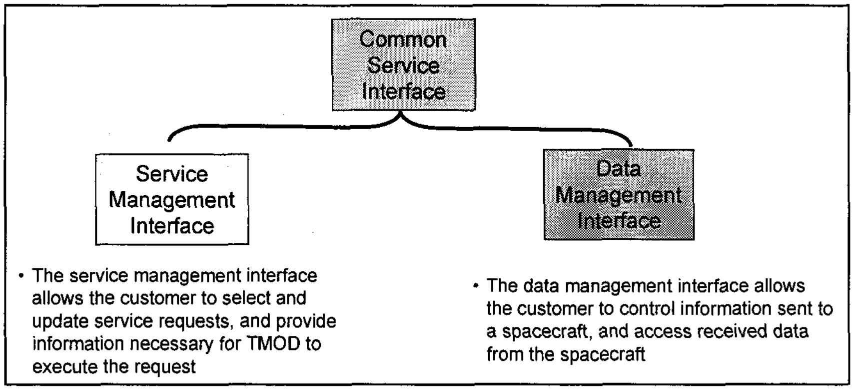


Figure 5 - Common Service Interface

Common Service Interface

The Common Service Interface is intended to provide DSMS users with a convenient path for accessing any information required by the user to understand and use DSMS services for mission support. More specifically, Common Service Interface supports identification of services, tools and engineering support needed for a mission, e.g., generation of service requests, access to schedulers/planners, and access to troubleshooters. It also provides the user with access and control over scheduled service instances providing a virtual direct link to spacecraft systems. The Common Service Interface provides customers with integrated on-line access to:

- information about DSMS services and capabilities
- tools that support planning for and use of the DSMS
- tools and a method for delivery of trajectory, telecommunications link design, and other mission data required by the DSMS
- status information regarding in process service requests
- tools and a method for transferring files (commands, sequences, goals, etc.) to be transmitted to a spacecraft
- data products that result from fulfilled service requests
- a direct connection to tracking stations via the Space Link Extension (SLE) protocol

The Common Service Interface is intended to be primarily a computer-based interface that offers DSMS customers "one stop shopping" for the most part, with human help available when needed. The intent of the interface design is to shield the customer from having to have detailed knowledge about how the DSMS performs its functions in order to use the DSMS. Inputs required from the customer would be the minimum needed to specify the service required.

Figure 6 illustrates a concept for the data management aspect of the Common Service Interface. In this view, a customer located wherever it is most convenient for the customer conducts a data exchange with the spacecraft data system. In the example, the user's applications are exchanging data products between ground and spacecraft systems. The use of files for transfer of the discrete products provides a form and functionality that simplifies the end to end handling, processing and accountability, but stream and message data are both accommodated by the CCSDS SLE protocol suite. Basically, the customer is placed in "virtual" control of the scheduled service instance, and following a handshake with the DSMS service management system via the DSMS-provided Web-based interface, exchange of data passes transparently through the DSMS with the protocol providing all underlying functions to assure full and complete communication, accounting and traceability.

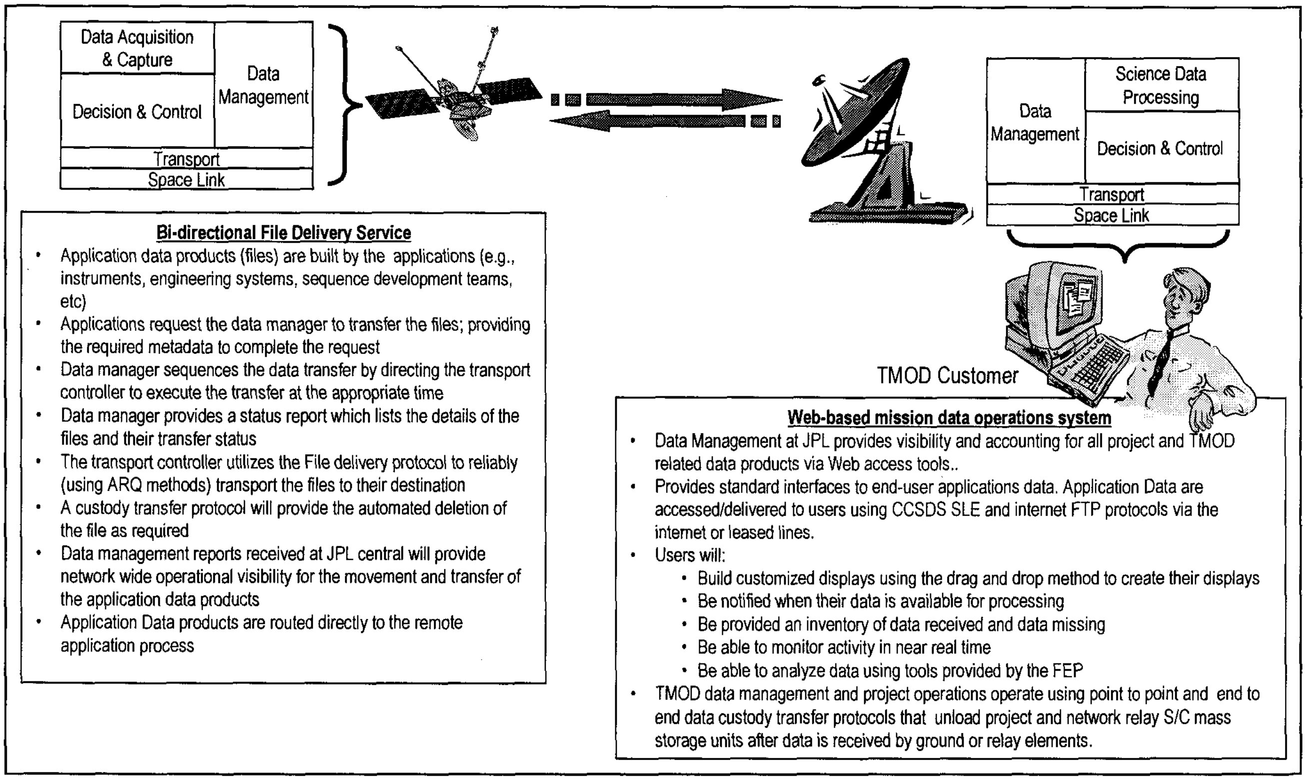


Figure 6 - Data Management Interface

Extended Service Interface

There is a class of services offered by the DSMS that uses multimission capabilities to perform functions for a mission that have historically depended on the use of mission dedicated personnel. The potential for a significant cost savings that may be realized through the use a shared work force to support more than one mission, together with tight budget pressures have caused customers to consider at least limited use of multimission services. These services include Flight Engineering, Sequence Engineering, Science Operations, and Navigation support, and they provide expert engineering support and specialized tools - just like a mission dedicated capability. The functions they provide are very intimate to a project, and the interface between these services and a using customer are likewise intimate and at a "people-level." The appearance of this interface depends greatly on the type and level of support subscribed to by a customer and the internal management structure of the customer's organization. The interface can be between the customer and a specific application team, a group of teams, or if the customer subscribes to a completely multimission solution, the interface can be between a TMOD MM and the Project's management. The exact nature of the interface is negotiated as part of the service level agreement during the early stages of mission planning.

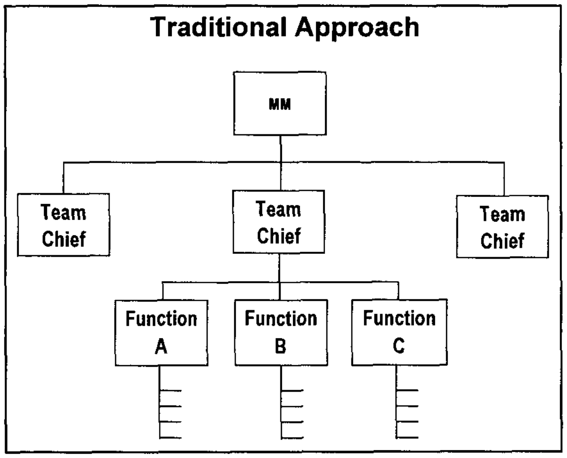
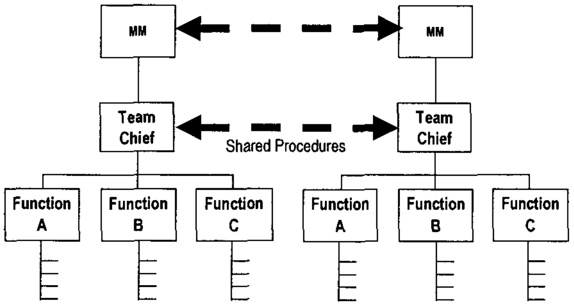


Figure 7 - Traditional Flight Operations Organization

To contrast these with a traditional mission operations organization, Figure 7 is provided for reference. This figure illustrates a flight operations organization with a hierarchical structure; i.e. a Mission Manager supported by dedicated teams that perform specific functions in support of the mission. While expensive in terms of labor costs, this organization has clear unambiguous lines of responsibility, control and authority. The personnel supporting the mission are negotiated for by the Project directly with the line organization that retains administrative responsibility for the individual.

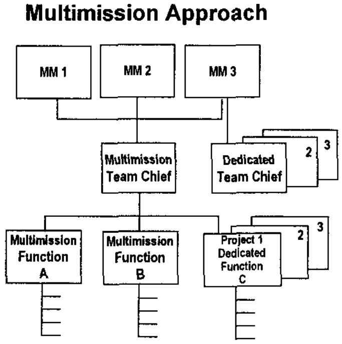
Use of multimission services coupled with Project partnerships and sharing of resources creates the possibility for a variety of multi-project and multimission organizational combinations. While the control provided by the traditional approach is highly desirable, the cost of this approach can be prohibitive to many, if not most, Projects. Cost considerations lead to multi-project arrangements, and make multimission arrangements more attractive. Figure 8 provides a contrast for some of the differences between a multi-project and multimission organizations.

Multi-Project Approach



- **Sharing of team members, tools, and procedures are between teams of multiple projects based on bilateral agreements**
- **Tools may be supplied to individual projects & adapted by SSM or the project**
- **Common procedures are defined by the sharing projects without SSM in the loop**
- **MM & Team Chiefs are programmatically accountable for the "capabilities" and the performance of the mission**
- **Teams are dedicated to each project**
- **MOS elements may be similar, but are controlled and evolved by each project**
- **Co-location of teams may occur**
- **Examples: Mars Missions, Stardust, Voyager/Ulysses**

Multimission Approach



- **Maximum sharing of teams, procedures, and tools**
- **Tools are SSM supplied**
- **Procedures are developed by the multimission Team Chief & endorsed by the SSM**
- **SSMs are programmatically responsible for insuring the quality of the multimission services**
- **Team Chiefs are jointly appointed by the SSM & MM**
- **Team Chiefs are technically accountable for the service instances to the MM**
- **Service instances are driven by customer's need**
- **There exists a multimission team structure**
- **Examples: Viking, Voyager, Outer Planets Project**

Figure 8 - Multi-Project/Multimission Contrast

Conclusion

The DSMS Operations Concept offers a distinct departure from a "business as usual" future for deep space mission operations. Based on a service system, driven by customer generated service requests, and utilizing a highly responsive, automated and reliable architecture, the DSMS will become an increasingly cost effective and efficient approach to spacecraft flight operations support.

Acknowledgement

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Biography

Mr. Spradlin has twenty-five years experience in system engineering, ground data system development, mission operations, and engineering management at JPL. He is currently the Chief Architect for Integrated Mission Operations Systems for the Telecommunications and Mission Operations Directorate at JPL. Mr. Spradlin holds a B.S. in Electronics Engineering and a M.S. in Management Science. He received the NASA Medal for Outstanding Leadership for his work on the Voyager Project.